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SELECTIVE HARMONIC ELIMINATION SWITCHING STRATEGY FOR BACK-TO-BACK STACKED MULTICELL CONVERTER

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ABSTRACT

This paper purposes the selective Harmonic Elimination Pulse Width Modulation (SHEPWM) strategy for the 17-level Back-To-Back Stacked Multicell Converter (BTBSMC) to improve the power quality by decreasing the Total Harmonic Distortion (THD). BTBSMC is the better converter to generate the higher number of output voltage levels with lower number of power electronic switches as compared to the other conventional converters. The control used in this paper eliminates the selective lower order harmonics which are adjusted in case of sector modulation control. Resultant theory is used to generate the angles with different modulation index .The simulation results has been carried out using SIMULINK/MATLAB present the effectiveness of the SHEPWM strategy for the proposed converter.

Keywords: Selective Harmonic Pulse width Modultion (SHEPWM), Total Harmonic Distortion (THD), Back-To-Back Stacked Multicell Converter (BTBSMC).

I. INTRODUCTION

In recent years, multilevel converters can be considered as a proven technology, widely used in medium/high power applications. By increasing the number of output levels we can decrease the total harmonic distortion [1]. These are commercialized products that power a wide range of applications, such as compressors, extruders, pumps, fans, grinding mills , rolling mills etc,.[1]. This is because the multilevel converters such as lower harmonic distortion and higher power quality which are obtained by increasing the number of output voltage levels [2]. Some of the fundamental multilevel topologies include the diode–clamped, flying capacitor, and cascaded H-bridge structures. Recently, with increase in the rating of the available switches. There has been much interest in new

topologies aiming to reduce the amount of semi conductor devices [6]. Depending on the switching frequency of multilevel converters , the switching stratagies can be classified into two catagories as high switching frequencies, including carrier based Sinusoidal Pulse Width Modulation (SPWM) and Space Vector Modulation (SVM) strategy and methods that work with low switching frequencies , generally equal to frequency of the fundamental component and generate staircase waveform representatives are Space Vector Control(SVC), Minimization of the Total Harmonic Distortion (MTHD)[6]

Generally, in SHEPWM technique, switching angles are calculated off-line through some famous algorithm such as: Harmonic Search Algorithm, Sequential Quadratic Programming, Homotopy Algorithm, Genetic Algorithm, Newton-Raphson (N-R),Resultant Theory. However Resultant Theory can find all solutions of the SHEPWM equation, analytically [2]. In this paper angles are obtained from resultant theory for various modulation index.

A major issue in the fundamental multilevel topology is to determine the switching topology is to determine the switching angles, to produce fundamental voltage as well as to eliminate specific higher order harmonics. By eliminating tis, we can observe that it is an efficient low total harmonic distortion inverter that can be used to interface distributed inverter dc energy sources to a main ac grid or traction drive powered by fuel cells [3].Transcendental equations characterizing the harmonic content can be converted into polynomial equations which can be solved by using resultant method from elimination theory[3].

II. BACK-TO-BACK STACKED MULTICELL CONVERTER

This topology consists of two stacked multicell converters that are connected back-to-back to each other by using two low frequency switches. In order to investigate the advantages of this topology, a comparison between the back-to-back topology and CM, FCM and SMC converters are presented. This comparison considers the number of high frequency and low frequency switches, number of capacitors and dc voltage sources for the same number of output voltage levels. Combination of one dc source and two semi conductor switches connected back-to-back with the dc source. 4-cell BTBSMC is as shown in Fig.1. Number of cells and output voltage can be calculated by using formulae below:

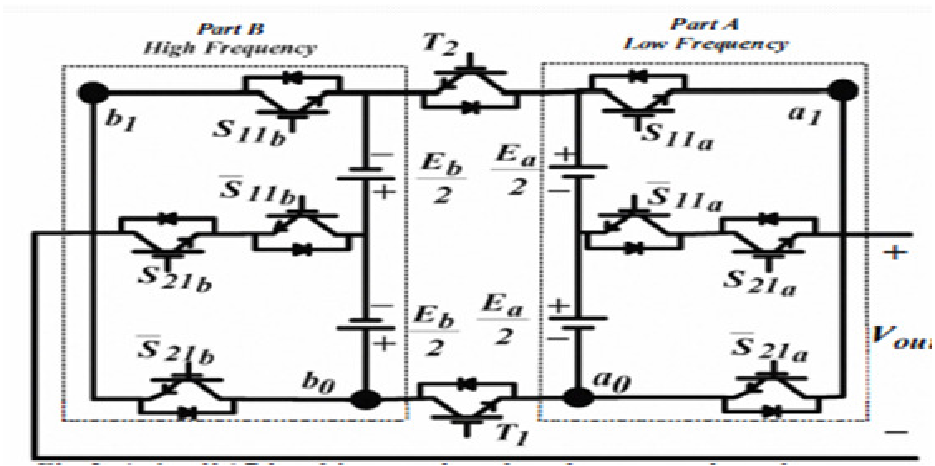

Fig.1. Block diagram for 4-cell BTBSMC

$N_{cell} =$ 2(n+m) (1)

$N_{level} =$ 2[(2n+1)(2m+1)]-1 (2)

Where E is the maximum output voltage. 2n and 2m are the numbers of cells which have been used in the part A and part B respectively [1]. The voltage values given to the dc sources

III. SWITCHING ALGORITHM

The Fourier series expansion of the stepped output voltage waveform of the multilevel converter as shown in figure.2.

$$V(\omega t) = \sum_{h=1,3,5,...}^{\infty} \frac{4E}{3n\pi}(\cosh\theta_1 + \cosh\theta_2 + ...+\cosh\theta_s)\sinh\omega t \quad (3)$$

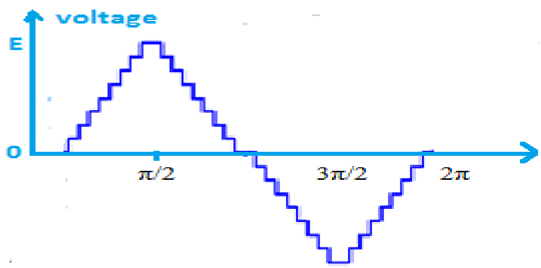

Fig.2. Output voltage waveform of 17-level multicell converter

Where 's' is the number of dc voltages, h is the harmonic number.

There are two methods available to choose the switching angles. one is to minimize the total harmonic distortion and other is to eliminate the lower frequency dominant harmonics. The main aim is to choose the switching angles to make the specific higher harmonics equal to zero and make the fundamental harmonic equal to the desired fundamental voltage. The triplen harmonics are automatically cancel in the line-to-line voltages.

The mathematical condition for this is

$$\begin{aligned}
&\frac{4E}{3\pi}(\cos\theta_1 + \cos\theta_2 + ...\cos\theta_4) = V_1 \\
&\cos 5\theta_1 + \cos 5\theta_2 + ...\cos 5\theta_4 = 0 \\
&\cos 7\theta_1 + \cos 7\theta_2 + ...\cos 7\theta_4 = 0 \\
&\cos 11\theta_1 + \cos 11\theta_2 + ...\cos 11\theta_4 = 0 \quad (4)
\end{aligned}$$

This is a system of three transcendental equations in the three unknowns $\theta_1, \theta_2, \theta_3, \theta_4$.To solve the above set of transcendental ,we have to use an iterative method such as the Newton-Raphson method, and other is to use resultant theory. For the 17-level converter would not contain fifth and seventh, eleventh order harmonic components.

IV. HARMONIC ELIMINATION METHOD

The system in eq(4) is of four transcendental equations with four unknowns $\theta_{1\,1},......\theta_4$.

Defone Cos θ_i = x_i

For i=1.2,3,4.

We can write the permutation for eqn(4) as

$$p_1(x) = x_1 + x_2 + x_3 + x_4 - m = 0$$
$$p_5(x) = \sum_{i-1}^{4}[5x_i - 20x_i^{\ 3} + 16x_i^{\ 5}] = 0$$
$$p_7(x) = \sum_{i-1}^{4}[-7x_i + 56x_i^{\ 3} - 112x_i^{\ 5} + 64x_i^{\ 7}] = 0 \tag{5}$$
$$p_{11}(x) = \sum_{i-1}^{4}[-11x_i + 220x_i^{\ 3} - 1232x_i^{\ 5} + 2816x_i^{\ 7} -$$
$$- 2816x_i^{\ 9} + 1024x_i^{\ 11}] = 0$$

Where
$x_i = (x_1, x_2, x_3, x_4)$

$$m = \frac{V_1}{\frac{S4V_{dc}}{\pi}} \tag{6}$$

Solution for this exists only specific ranges of modulation index

$$m_a = m / s \tag{7}$$

The set of equations has 4 unknowns, the solution must be satisfy $0 \le x_4 < x_3 < x_2 < x_1 \le 1$ For four dc sources the polynomials $p_1(x)$,$p_5(x)$,$p_7(x)$,$p_{11}(x)$ in the equation are symmetric polynomials and the elementary symmetric functions s_1,s_2,s_3,s_4 are defined as

$$s_1 \cong x_1 + x_2 + x_3 + x_4$$
$$s_2 \cong x_1x_2 + x_1x_3 + x_1x_4 + x_3x_2 + x_4x_2 + x_3x_4$$
$$s_3 \cong x_1x_2x_3 + x_1x_2x_4 + x_1x_4x_3 + x_4x_2x_3 \tag{8}$$
$$s_4 \cong x_1x_2x_3x_4$$

Rewriting the polynomials $P_i(x)$ in terms of the elementary symmetric polynomials gives

$$p_1(s) = s_1 - m = 0$$
$$p_5(s) = 5s_1 - 20s_1^{\ 3} + 16s_1^{\ 5} + 60s_1s_2 - ......$$
$$p_7(s) = -7s_1 + 56s_1^{\ 3} - 112s_1^{\ 5} + 64s_1^{\ 7} .....$$
$$p_{11}(s) = -11s_1 + 220s_1 - 123216s_1^{\ 5} + ...$$
$$(9)$$

For the solution
We have to eliminate the s_1 first so that

$$p_1(s) = s_1 - m = 0$$
$$q_5(s_2, s_3, s_4) \cong p_5(m, s_2, s_3, s_4)$$
$$q_7(s_2, s_3, s_4) \cong p_7(m, s_2, s_3, s_4) \tag{10}$$
$$q_{11}(s_2, s_3, s_4) \cong p_{11}(m, s_2, s_3, s_4)$$

Where

Function	Deg s_2	Deg s_3	Deg s_4
$q_5(s)$	2	1	1
$q_7(s)$	3	2	1
$q_{11}(s)$	5	3	2

Degree of $p_1(x)$,$p_5(x)$,$p_7(x)$,$p_{11}(x)$ are shown in the table below

Function	Degree in x_1, x_2, x_3, x_4
$p_5(x_1, x_2, x_3, x_4)$	5
$p_7(x_1, x_2, x_3, x_4)$	7
$p_{11}(x_1, x_2, x_3, x_4)$	11

Each of $q_i(s)$ has its maximum degree in s_2. To reduce the overall burden we have to eliminate 's_4' by computing

$$\begin{aligned} r_{q5,q7}(s_2,s_3) &= \mathrm{Res}(q_5(s_2,s_3,s_4)q_7(s_2,s_3,s_4),s_4) \\ r_{q5,q11}(s_2,s_3) &= \mathrm{Res}(q_5(s_2,s_3,s_4)q_{11}(s_2,s_3,s_4),s_4) \end{aligned} \qquad (11)$$

Where

Function	Deg s_2	Deg s_3
$r_{q5,q7}(s_2, s_3)$	2	2
$r_{q5,q11}(s_2, s_3)$	4	3

Finally eliminating s_3 from $r_{q5,q7}(s_2,s_3)$ and $r_{q5,q11}(s_2,s_3)$ one obtains the resultant polynomial

$$r(s_2) \cong \mathrm{Re}\,s(r_{q5,q7}(s_2,s_3), r_{q5,q11}(s_2,s_3)) \qquad (12)$$

Which is only degree of two in s_2.For each m, we have to solve $r_{q5,q7}(s_2) = 0$

V. SYMMETRICAL POLYNOMIALS

For each solution (s_1, s_2, s_3, s_4) has the corresponding values of (x_1, x_2, x_3, x_4) are required to obtain the switching angles.

So we can use the resultant method to solve the system polynomials.

$$\begin{aligned} & f_1(x_1,x_2,x_3,x_4) = s_1 - (x_1,x_2,x_3,x_4) = 0 \\ & f_2(x_1,x_2,x_3,x_4) = s_2 - (x_1x_2 + x_1x_3 + x_1x_4 + x_3x_2 + \\ & x_4x_2 + x_3x_4) = 0 \\ & f_3(x_1,x_2,x_3,x_4) = s_3 - (x_1x_2x_3 + x_1x_2x_4 + x_1x_3x_4) = 0 \\ & f_4(x_1,x_2,x_3,x_4) = s_4 - (x_1x_2x_3x_4) = 0 \end{aligned} \qquad (13)$$

We can compute

$$r_1(s_2,s_3) = \operatorname{Re} s(f_1(x_2,x_3,x_4), f_2(x_2,x_3,x_4), x_4)$$
$$r_2(s_2,s_3) = \operatorname{Re} s(f_1(x_2,x_3,x_4), f_2(x_2,x_3,x_4), x_4) \quad (14)$$

So that

$$r_1(s_2) = \operatorname{Re} s(r_1(x_2,x_3), r_2(x_2,x_3), x_3) \quad (15)$$

Replace the solution of eqn(14) in eqn(15) then solve for the roots. Finally solve the equation and check

$$0 \le x_4 < x_3 < x_2 < x_1 \le 1$$

By using the fundamental switching scheme in Fig.2.,the solutions were computed and plotted as shown in the figure.3.

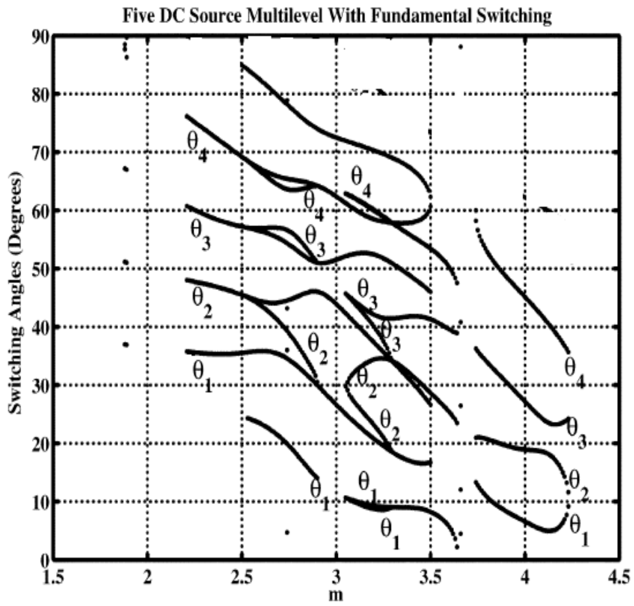

Fig.3. m versus switching angles for the four source converter

This method is based on the theory of resultants of polynomials. The parameter m was incremented in steps of 0.02. It is important observe that m must be approximately in the range of 1.5 to 1.8. There are three different sets of solutions to solve equation (1). Those are m in the interval [0.8,1.12],[2.12,2.19] and[2.50.2.8].The solution which gives the better harmonic distortion is the selected one.

VI. SIMULATION MODEL

By using MATLAB SIMULINK simulation is verified for the well performance of 17-level Back-To-Back Stacked Multicell Converter by proposed switching algorithm. The fig.3. indicates the simulink diagram of 17-level BTBSMC .

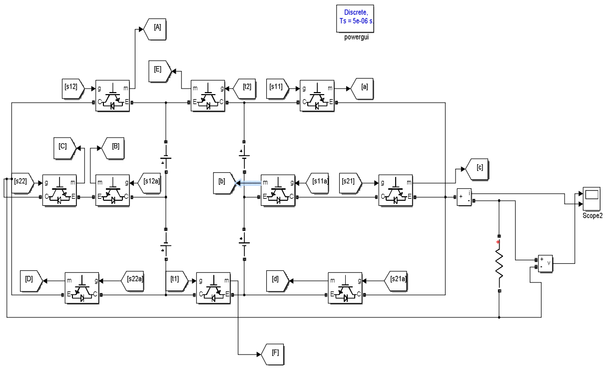

Fig.4. Simulink Diagram of 4-cell,17-level BTBSMC

VII. SIMULATION RESULTS

Test I

The simulating circuit is simulated by using MATLAB and the waveform observe is a seventeen level stepped output as shown in fig.5.

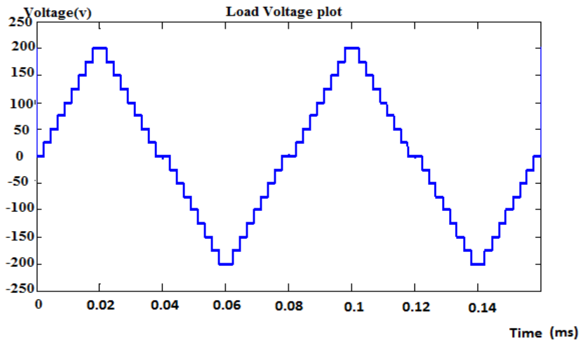

Fig.5. Output voltage waveform of 17-level BTBSMC

Test II

The BTBSMC is simulated by adjusting the modulation index m as 1 then the resulting output waveform is obtained as shown in fig.6.

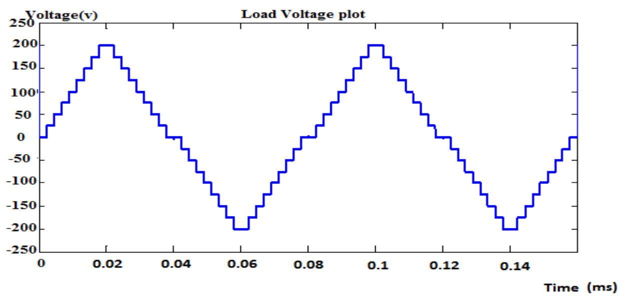

Fig.6. Output voltage of a 17-level BTBSMC for m=1

Test III

The BTBSMC is simulated by adjusting the modulation index m as 0.5 then the resulting output waveform is obtained as shown in fig.7.

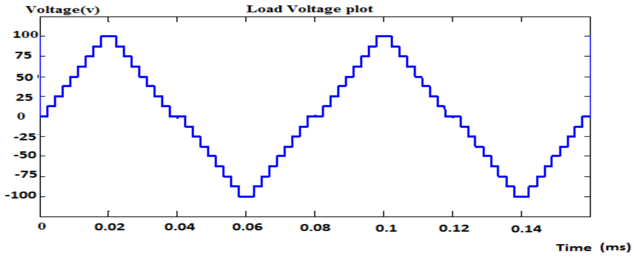

Fig.7. Output voltage of a 17-level BTBSMC for m=0.5

Test IV

The BTBSMC is simulated by adjusting the modulation index m as 0.25 then the resulting output waveform is obtained as shown in fig.8.

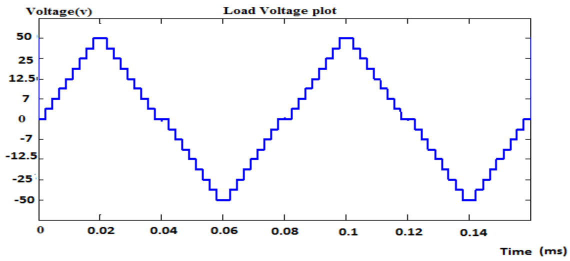

Fig.8. Output voltage of a 17-level BTBSMC for m=0.25

HORMONIC ANALYSIS

To observe the power quality improvement of the voltage level which was obtained by the converter, Harmonic analysis is conducted by using powergui FFT analysis. The Total Harmonic Distortion calculation results are observed as follows for different modulation index.

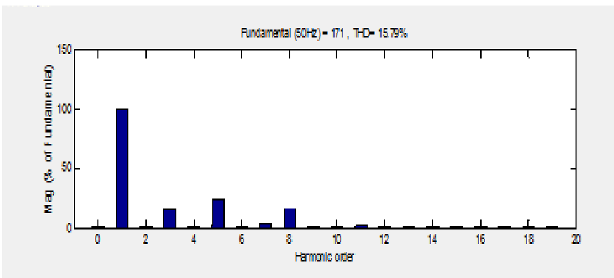

Fig.9. FFT window of output voltage for 17-level BTBSMC without adjusting modulation index

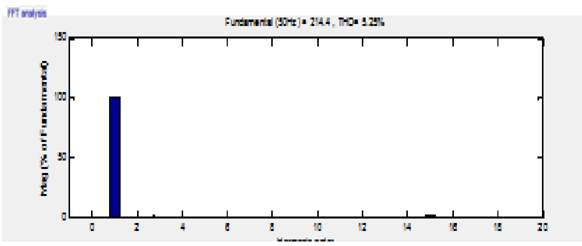

Fig.10. FFT window of output voltage for 17-level BTBSMC with modulation index m=1

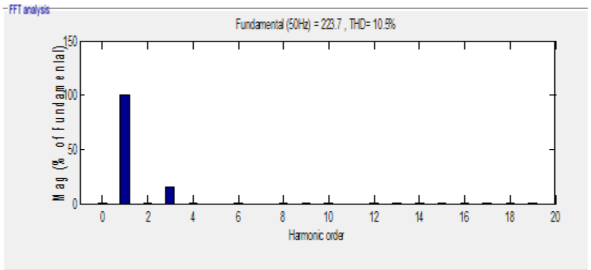

Fig.11. FFT window of output voltage for 17-level BTBSMC with modulation index m=0.5

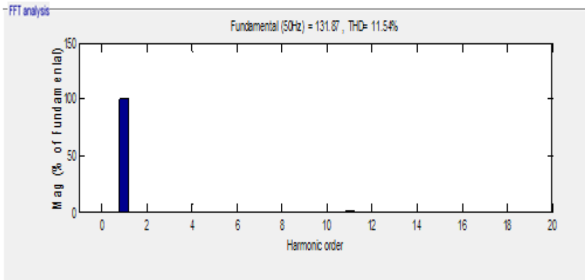

Fig.12.FFT window of output voltage for 17-level BTBSMC with modulation index m=0.25

VIII. CONCLUSIONS

The Back-To-Back Stacked Multicell Converter with selective harmonic elimination is effective converter to improve power quality over sector modulated control. The control used in this paper eliminates the lower order harmonics to decrease THD. There is a scope to improve the modulation index for specific range by finding the new method in the place of resultant theory.

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